

Health Risks from Acid Rain: A Canadian Perspective

by Claire A. Franklin,* Richard T. Burnett,* Richard J. P. Paolini,* and Mark E. Raizenne*

Acidic deposition, commonly referred to as acid rain, is causing serious environmental damage in eastern Canada. The revenues from forest products, tourism and sport fishing are estimated to account for about 8% of the gross national product. The impact on human health is not as clearcut and a multi-department program on the Long-Range Transport of Airborne Pollutants (LRTAP) was approved by the federal government in June 1980. The objectives of the LRTAP program are to reduce wet sulfate deposition to less than 20 kg/ha per year in order to protect moderately sensitive areas. This will require a 50% reduction in Canadian SO₂ emissions east of the Saskatchewan/Manitoba border and concomitant reductions in the eastern U.S.A. The objectives of the health sector of the program are to assess the risk to health posed by airborne pollutants which are subjected to long-range transport and to monitor the influence of abatement programs.

Two major epidemiology studies were undertaken in 1983, one in which the health effects related to acute exposure to transported air pollutants were studied in asthmatic and nonasthmatic children, and another in which the effects of chronic exposure to these pollutants were studied in school children living in towns with high and low levels of pollutants. Preliminary analysis of the data do not indicate major health effects, but definitive conclusions must await final analysis. Studies on the indirect effects of acid deposition on water quality have shown that acidified lake water left standing in the plumbing system can adversely affect water quality and that federally set guidelines for copper and lead are exceeded. Flushing of the system before using the water rectifies the situation. Additional studies are planned to further delineate the magnitude of the health effects of acidified lake water.

Introduction

Issues

Acid rain is causing serious damage to the environment and the resources of eastern Canada. Considerable progress has been made over the past three years in defining the nature, causes and solutions of this problem, and major reductions in emissions of sulphur dioxide in both Canada and the United States are being sought.

The natural resources at risk from acid rain sustain vital components of the Canadian economy and contribute to our quality of life. Over 40% of the lakes surveyed in Ontario and Quebec are vulnerable and many are already showing critical signs of damage. In Nova Scotia, 30% of the salmon rivers have been affected. About 50% of the forest growth and agricultural production in eastern Canada is located in areas receiving excessive acid deposition (1). The revenues potentially at risk in-

clude those from forest products, tourism, and sport fishing and account for about 8% of the Canadian gross national product (2). Available scientific information provides a sufficient basis to design and implement abatement programs to protect moderately sensitive lakes and streams. Further work is required to do the same for sensitive lakes and streams, forests, agriculture, buildings and human health.

In Canada, the federal legislation controlling air pollution is the Clean Air Act under which ambient air quality objectives are set. Amendments of the Canadian Clean Air Act in December 1980 (3), gave the federal government authority to control transboundary pollution originating in Canada. However, the provinces are given the first opportunity to enforce standards to prevent transboundary pollution under their own legislation. The act was further amended at this time to give the Minister of the Environment authority to recommend site-specific standards for sources that "may reasonably be anticipated to constitute a significant danger to the health, safety, or welfare of persons in another country." The ambient air quality objectives for air pol-

*Environmental Health Directorate, Department of National Health and Welfare, Ottawa, Ontario, Canada K1A 0L2.

Table 1. Current health-related national ambient air quality objectives.

Pollutant	Canada (maximum acceptable level)		United States	
	Level	Time	Level	Time
Ozone (O ₃)	0.08 ppm 0.025 ppm 0.015 ppm	1 hr 24 hr Annual ^b	0.12 ppm (235 µg/m ^{3a})	1 hr
Nitrogen oxides (NO ₂)	0.21 ppm 0.11 ppm 0.05 ppm	1 hr 24 hr Annual ^b	0.05 ppm (100 µg/m ³)	Annual ^b
Sulfur oxides (SO ₂)	0.34 ppm 0.11 ppm 0.02 ppm	1 hr 24 hr Annual ^d	0.14 ppm (365 µg/m ³)	24 hr ^c
			0.03 ppm (80 µg/m ³)	Annual
Suspended particulate matter	120 µg/m ³ 70 µg/m ³	24 hr Annual	260 µg/m ³ 75 µg/m ^{3e}	24 hr ^c Annual ^d

^a The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 235 µg/m³ is equal to or less than 1.

^b Annual arithmetic mean.

^c Not to be exceeded more than once per year.

^d Annual geometric mean.

^e Currently under review and possible revision.

lutants which are affected by long range transport are shown in Table 1. It should be noted that in both Canada and the U.S. only the source emissions are legislatively controlled and not the subsequent transformation products.

The initial steps in a collaborative approach to the continental LRTAP problem were taken in 1978 when the U.S. Congress passed a resolution requiring the U.S. State Department to negotiate an air quality agreement with Canada. This resolution was later incorporated into the U.S. Foreign Relations Authorization Act. A joint statement on Transboundary Air Quality emphasizing LRTAP and acid rain was issued by the Canadian and United States Governments in July 1979. In August 1980, the Memorandum of Intent was signed and negotiations to achieve a transboundary air pollution control agreement began on June 23, 1981. In February 1982, Canada offered to reduce SO₂ emissions by 50% by 1990 at an estimated cost of \$1 billion if similar action was taken in the U.S. This was rejected by the U.S. on the grounds that a 50% reduction would cost the U.S. a disproportionate \$2.5 to 4 billion. The per capita cost to Canadians would have been 3 to 4 times larger than to Americans. Canada is already committed to a 50% reduction of SO₂ emissions by 1994 which includes abatement measures at INCO in Sudbury, Ontario Hydro, and Noranda's copper smelter in Rouyn-Noranda, Quebec.

In March 1984, Charles Caccia, Minister of the Department of the Environment, stated "we will proceed independently from the United States in developing a Canadian solution on the matter of acid rain and we hope that the U.S. will join us at the earliest possible date" (2). In order to achieve the tolerable level of wet sulfate deposition of 20 kg/ha per year, the sensitive areas of Eastern Canada will require emission reduc-

tions of up to 50% in Canada and major reductions in the United States.

At this meeting of environment ministers, Canada, Austria, Denmark, West Germany, Finland, France, the Netherlands, Norway, Sweden, and Switzerland agreed to a 30% reduction of national levels of SO₂ by 1993. In July 1984, at an International Acid Rain Conference in Munich, East Germany, Bulgaria, and the U.S.S.R. agreed to 30% levels of SO₂ by 1990.

A recent Gallup poll (March 1984) in Canada, showed that 78% of Canadians consider acid deposition is a serious problem and 74% consider that the government should assist in achieving adequate reductions on emissions; 69% were even willing to contribute money to help alleviate the problem.

Current LRTAP Program

A multidepartment program on the Long-Range Transport of Airborne Pollutants (LRTAP) was approved in June 1980. There are four interrelated sections in the program: program management, public information program, socioeconomic program, and technical program (control strategy and science). The objectives of the LRTAP program are to: reduce wet sulfate deposition to less than 20 kg/ha per year to protect moderately sensitive areas (a 50% reduction in sulfur dioxide emissions east of the Saskatchewan/Manitoba border and in the eastern United States is required); and secure the necessary emission reductions in Canada and the U.S., to support public information efforts (particularly in the U.S.), to monitor deposition and effects and to provide the data necessary to refine abatement programs. The objectives of the health sector of the program are to assess the risk to health posed by airborne pollutants which are subjected to long-

Table 2. Summary of emissions for North America for 1980.

Source	Canada, 10 ⁶ tons/yr		United States, 10 ⁶ tons/yr	
	SO ₂	NO _x	SO ₂	NO _x
Electric utilities	0.7	0.2	15.8	5.6
Nonferrous smelters	2.1		1.4	
Industrial/residential commercial heating	0.8	0.4	3.2	4.2
Transportation	0.2	1.1	0.8	8.5
Other industrial pro- cesses	0.9	0.1	2.9	1.0
Total	4.7 ^a	1.8 ^b	24.1	19.3

^a 16% of North American total SO₂.

^b 9% of North American total NO_x.

range transport and to monitor the influence of abatement programs on human health.

Sources of Acidic Pollutants

Acidic deposition has been a concern in Canada since the early seventies, when the adverse effects on aquatic ecosystems were well documented (4-7). The problem appears to be related to the emissions and subsequent

atmospheric fallout of sulfur and nitrogen oxides.

Although much attention has focussed on the depression of precipitation pH, the dry deposition of gases can also contribute significantly to the acidification process (4). Both sulfur and nitrogen oxides are released into the atmosphere from point sources, after which they are further oxidized to form sulfuric and nitric acids. These and other associated transformation products may then be transported great distances and subsequently deposited in regions remote from their source.

Natural sources of sulfur and nitrogen oxides are also present, but anthropogenic sources account for the majority of sulfur and nitrogen that occurs in ambient air over heavily populated regions of North America. Table 2 illustrates the relative amount of SO₂ and NO_x emitted by various industrial/residential sectors and also compares the emissions in both Canada and the United States. Figures 1 and 2 represent the total emissions within each 160 km² of eastern North America.

Nitrogen oxide emissions in both Canada and the U.S. are primarily associated with urban centers and transportation whereas SO₂ emissions are from industrial sources. In the United States SO₂ emissions are related to the production of electricity in coal-fired power plants. The top 50 plants in Eastern North American

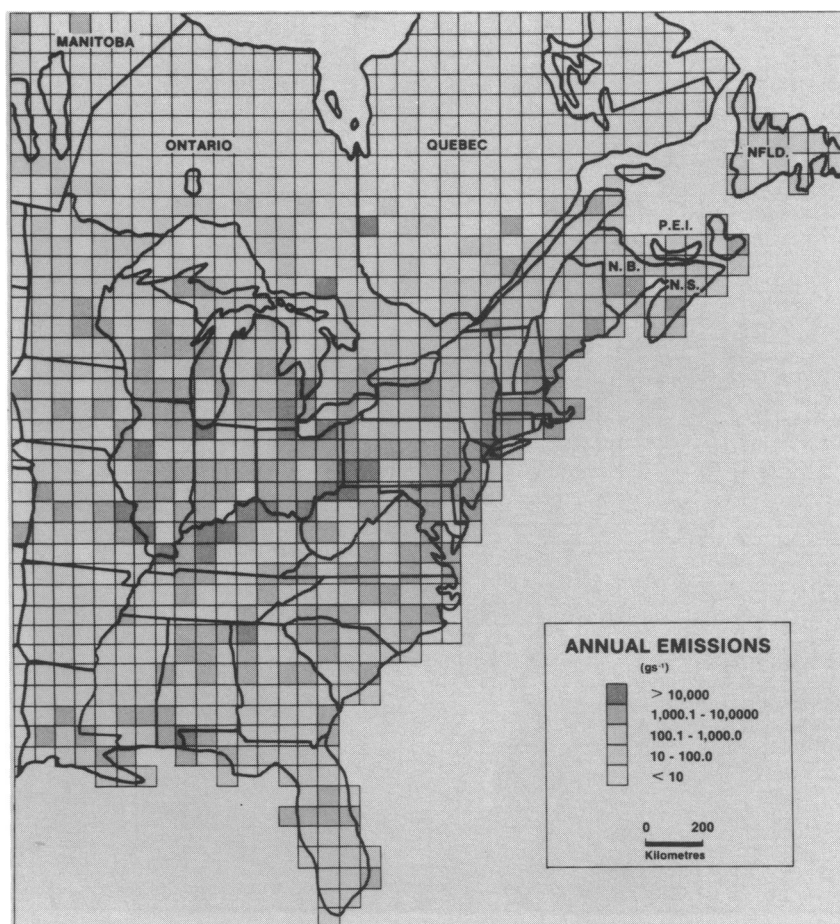


FIGURE 1. Magnitude and distribution of sulfur dioxide emissions in eastern North America (10).

are shown in Table 3. Three Ontario plants are also included. The emissions from the plants in Ontario are considerably higher than those from plants in the other nine provinces (Table 4). The major sources of SO₂ emissions in Canada (45%) are the nonferrous smelters with the INCO smelter, Copper Cliff, being the largest single source in Canada (Table 5).

The translocation, transformation and deposition in far removed areas are of major concern to the LRTAP program. The translocation of these polluted air masses is shown in Figures 3 and 4, which typify the seasonal nature of wind patterns throughout North America. Although it is true that these represent only surface level air movements, upper air streams associated with LRTAP generally follow similar patterns. When Figures 3 and 4 are superimposed onto Figures 1 and 2, a picture of emission and possible deposition can be obtained.

When deposition indices are applied to these data (Figs. 5 and 6), as well as to the pH precipitation (Fig 7) it is evident that the regions receiving the highest levels of LRTAP lie in a northerly and easterly direction in relation to the high emission point sources.

Estimated Risk

A model to estimate the number of excess deaths due to sulfurous air pollution has been developed by Hamilton (12). He estimated that 50,774 excess deaths (with a 90% range of 0 to 159,950) in the United States and Canada could be attributed to acid rain. In Canada, the predicted number of excess deaths was 4,076 (with a 90% range of 0 to 12,125). A breakdown of exposure levels and excess deaths by region in Canada as derived from his data is shown in Table 6. The provinces with the highest potential LRTAP and local exposures (Ontario and Quebec) show the highest anticipated health impact.

The model developed by Hamilton (12) is a complex function of both local and long-range air pollution, regional population patterns and many other demographics. The model is based on 1980 population levels and 1978 pollution emissions data. A health-damage function developed by Morgan et al. (13) addresses uncertainties in health outcomes by providing a range of mortality estimates for a given population exposure level. The health-damage function used is essentially a compilation

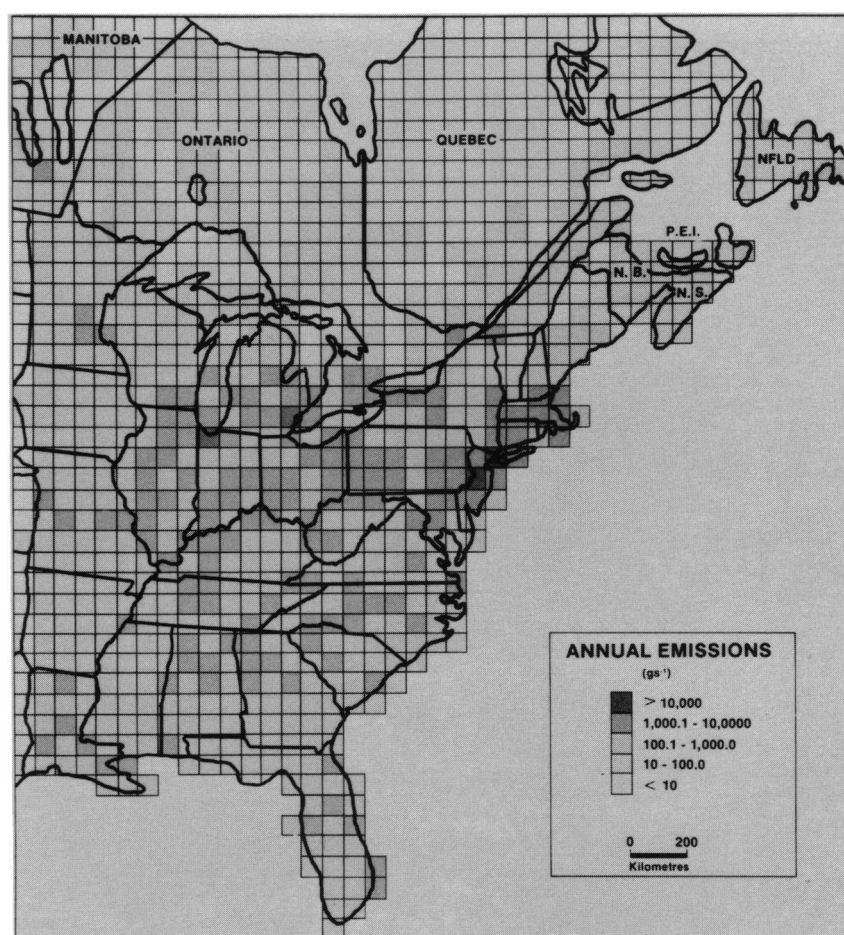


FIGURE 2. Magnitude and distribution of nitrogen oxide emissions in eastern North America (10).

Table 3. Top 50 coal-fired power plants in eastern North America ranked according to total SO₂ emissions in 1979^a

Rank	Plant	State/province	Country	Estimated SO ₂ emission, 10 ³ metric tons/yr
1	Paradise	Kentucky	U.S.A.	372.5
2	Muskingum	Ohio	U.S.A.	340.2
3	Gavin	Ohio	U.S.A.	339.5
4	Cumberland	Tennessee	U.S.A.	289.7
5	Monroe	Michigan	U.S.A.	264.8
6	Clifty Creek	Indiana	U.S.A.	263.7
7	Gibson	Indiana	U.S.A.	261.1
8	Baldwin	Illinois	U.S.A.	257.9
9	Labadie	Missouri	U.S.A.	224.0
10	Kyger Creek	Ohio	U.S.A.	205.5
11	Bowen	Georgia	U.S.A.	202.6
12	Conesville	Ohio	U.S.A.	186.8
13	Mitchell	West Virginia	U.S.A.	186.2
14	Hatfields	Pennsylvania	U.S.A.	167.3
15	New Madrid	Missouri	U.S.A.	164.0
16	Sammis	Ohio	U.S.A.	160.7
17	Lambton	Ontario	Canada	160.2
18	Wansley	Georgia	U.S.A.	159.7
19	Homer City	Pennsylvania	U.S.A.	159.1
20	Johnsonville	Tennessee	U.S.A.	157.9
21	Nanticoke	Ontario	Canada	155.0
22	Gaston EC	Alabama	U.S.A.	154.8
23	Montrose	Missouri	U.S.A.	147.1
24	Harrison	West Virginia	U.S.A.	142.8
25	Brunner Isl.	Pennsylvania	U.S.A.	142.0
26	Coffeen	Illinois	U.S.A.	141.8
27	Cardinal	Ohio	U.S.A.	140.8
28	Eastlake	Ohio	U.S.A.	137.4
29	Kammer	West Virginia	U.S.A.	136.8
30	Kincaid	Illinois	U.S.A.	136.3
31	Keystone	Pennsylvania	U.S.A.	127.2
32	Stuart J.M.	Ohio	U.S.A.	125.6
33	Cayuga	Indiana	U.S.A.	121.7
34	Shawnee	Kentucky	U.S.A.	111.0
35	Gallatin	Tennessee	U.S.A.	110.6
36	Montour	Pennsylvania	U.S.A.	109.4
37	Big Bend	Florida	U.S.A.	109.2
38	Conemaugh	Pennsylvania	U.S.A.	108.9
39	Widows Creek	Alabama	U.S.A.	106.0
40	Amos	West Virginia	U.S.A.	105.2
41	Thomas Hill	Missouri	U.S.A.	104.9
42	Joppa Steam	Illinois	U.S.A.	104.9
43	Mt. Storm	West Virginia	U.S.A.	102.5
44	Petersburg	Indiana	U.S.A.	100.7
45	Beckjord	Ohio	U.S.A.	99.7
46	Avon Lake	Ohio	U.S.A.	98.0
47	Fort Martin	West Virginia	U.S.A.	94.6
48	Miami Fort	Ohio	U.S.A.	94.2
49	Lakeview	Ontario	Canada	91.4
50	Yates	Georgia	U.S.A.	88.8

^aPower plants were considered from Ontario and 32 eastern U.S. States. The statistics are from Ontario Hydro and the U.S. Department of Energy; the analysis was performed by the Ontario Ministry of Environment, Air Resources Branch.

of expert opinion of five epidemiologists concerning the relationship between sulfate pollution and premature mortality. The range reflects the controversy over the validity of epidemiological studies suggesting a relationship between mortality and air pollution levels. It includes estimates from epidemiologists who believe there is a negligible effect at prevailing sulphate concentrations as well as those believing there are signif-

icant adverse effects on human health at these exposure levels. This model needs further investigation to fully determine its validity.

The uncertainty in the model is reflected in the large range (0 to about 12,000) in the predicted number of excess deaths. Future epidemiological and toxicological studies designed to reduce this uncertainty would be of considerable value.

Table 4. Emissions from thermal power generation in 1980.^a

Province	SO ₂ , tons	NO _x , tons
British Columbia	646	4,528
Alberta	35,073	35,585
Saskatchewan	36,998	37,679
Manitoba	2,652	3,199
Ontario	397,502	100,960
Quebec	1,957	2,360
New Brunswick	122,353	16,808
Nova Scotia	124,249	39,342
Prince Edward Island	3,013	1,045
Newfoundland	20,462	3,663
Canada total	744,899	245,187

^a Source: Sub-Committee Report on Acid Rain (8).

Health Effects

Elevated levels of air pollution have caused increased morbidity and mortality in Europe and in North America. However, no single agent has been irrevocably indicated as the cause for these excess health outcomes (14).

Although the database is far from complete, it has been concluded that oxides of sulfur and nitrogen as well as ozone are toxic to humans. These conclusions

Table 5. Ten largest sources of sulfur dioxide (SO₂) for Canada.^a

Sources	SO ₂ , tons/yr
INCO Ltd., Copper Cliff, Ontario	866,000
Noranda Mines Ltd., Noranda, Québec	538,000
INCO Ltd., Thompson, Manitoba	359,000
Hudson Bay Mining and Smelting Co., Flin Flon, Manitoba	212,000
Ontario Hydro, Lambton Station, Courtwright, Ontario	160,000
Ontario Hydro, Nanticoke Station, Walpole Township, Ontario	155,000
Algoma Steel Corporation Ltd., Wawa, Ontario	141,000
Falconbridge Nickel Mines Ltd., Falconbridge, Ontario	122,000
Suncor Inc. (Oil Sands Division), Fort McMurray, Alberta	93,000
Ontario Hydro, Lakeview Station, Mississauga, Ontario	91,000

^a Environment Canada (9).

have been drawn from information gathered from epidemiological, human volunteer, and animal studies in which these primary pollutants have been tested. Unfortunately, there are few if any studies on the atmospheric transformation products.

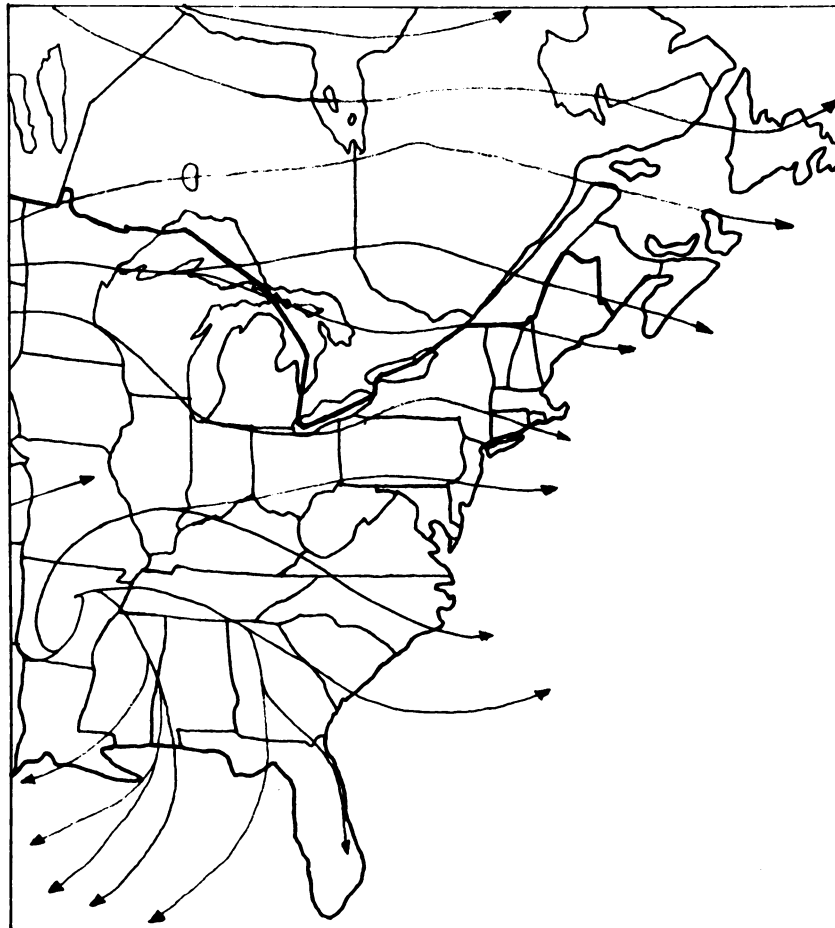


FIGURE 3. Wind patterns for North America based on surface streamlines for January (11).

Table 6. Health impacts in Canada based on 1980 population levels and 1978 pollution data.

Region	Sulfate exposure, million person- $\mu\text{g}/\text{m}^3$	Excess mortality	
		Median	90% range ^a
British Columbia	2	79	0-236
Alberta and Saskatchewan	5	168	0-500
Manitoba	2	63	0-189
Ontario	57	2094	0-6227
Sudbury, Ontario	1	27	0-82
Quebec	34	1248	0-3710
Nova Scotia and PEI	5	196	0-583
New Brunswick	4	150	0-447
Newfoundland and Labrador	1	51	0-151
Total	111	4076	0-12,125

^aBased on the central 90% of the distribution of estimates. Data of Hamilton (12).

The primary target organ for the predepositional effects is the lung. Both gases and particles, alone or in combination, have unique physiochemical properties which are capable of challenging the respiratory defense mechanisms. Groups at increased risk to adverse health effects from air pollutants include persons with pre-existing cardiorespiratory disease, especially the elderly, infants, and young children.

Oxides of sulfur are known bronchoconstrictors and increases in flow resistance can be shown in healthy individuals after exposure to 1, 5, and 25 ppm SO_2 (15). Epidemiological evidence has suggested that the observed effects from sulfate exposure are more likely related to the hydrogen ion concentration (16).

The deep lung irritation effects of NO_2 are well known. There are virtually no studies on the effects of

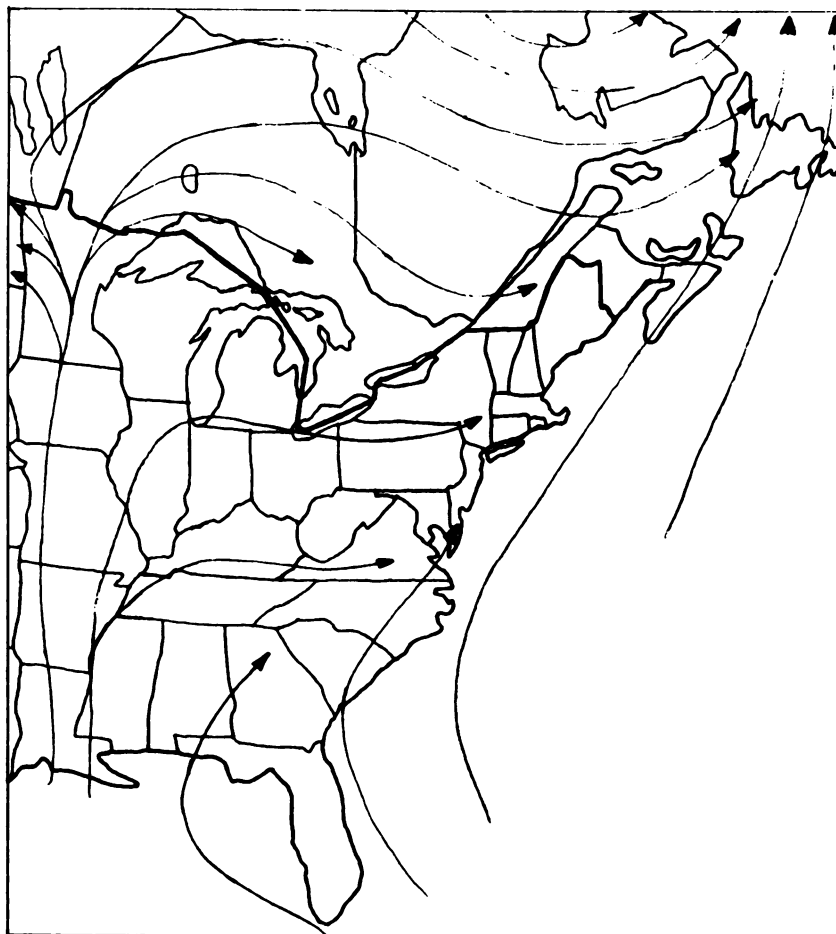


FIGURE 4. Wind patterns for North America based on surface streamlines for July (11).

nitric acid (17) and only limited data on particulate nitrogen oxides. Studies on sodium nitrates have not shown any significant detrimental effects (18–20).

Ozone which is formed as a photochemical reaction product of organic chemicals and free radical and nitrogen oxides is readily transported long distances and is not necessarily indicative of point source emission. It is irritating to eyes, nose and throat at 0.1 to 0.15 ppm (21) and significant health effects are found above 0.37 ppm.

Other pollutants are believed to potentiate the effects of ozone (22–25). It is possible that there will be additional interactions between chemicals in the complex mixture of transformation products. Thus regulations based on the effects of single pollutants may well be inadequate.

The program to assess potential health effects related to acid deposition undertaken by the Department of National Health and Welfare has focussed on ascertaining the effects of acute and chronic exposures to LRTAP pollutants on respiratory function in school children as well as on the impact of acid deposition on drinking water quality.

Predeposition Direct Effects

Acute Study

Design. An intensive 10 day investigation into the possible health effects associated with fluctuations in ambient air pollution and meteorological parameters was undertaken at the Lake Couchiching Summer Camp, Ontario, June 29 to July 9, 1983. This was a residential summer camp located approximately 100 km north of Toronto, Canada, at a site remote from major industrial, automotive and fossil-fuel generating stations. Furthermore, this region has shown ecological damage due to acidic deposition.

The study had both health and pollutant monitoring components. The health assessment included a pre-camp clinical evaluation, a telephone administered questionnaire on respiratory health history, twice daily lung function measurements, daily symptomatology questionnaire, and assessments of activity level during camp activities. Continuous air pollution monitoring was performed on-site by the Harvard School of Public Health. Pollutants measured included: O_3 , respirable particles,

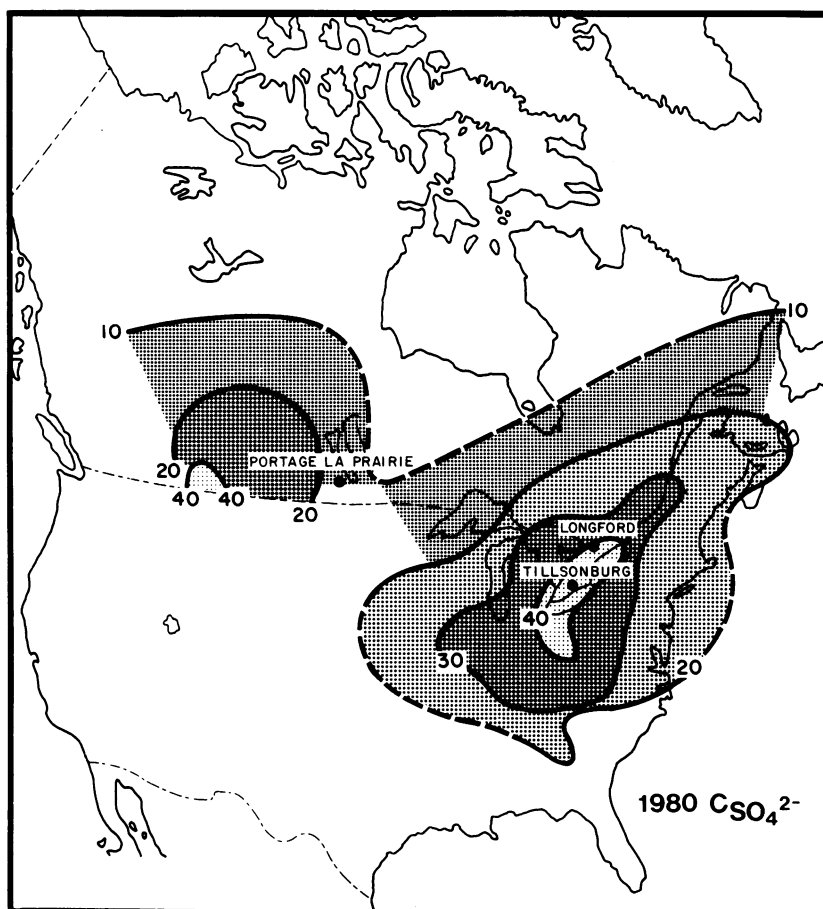


FIGURE 5. Precipitation amount-weighted mean sulfate ion concentration for 1980 ($\mu\text{mole/L}$) (10).

sulfates, NO_2 , and SO_2 . Meteorological measurements were also performed on-site by Environment Canada.

Fifty-two campers volunteered to participate and completed the study. Twenty-three subjects were asthmatics, sponsored to the camp by the Asthma Society of Canada.

Statistical Analysis of Lake Couchiching Data. The effects of air pollution and meteorological factors on lung function of both asthmatics and non-asthmatics are being examined by multiple linear regression analysis relating lung function performance measurements to daily pollution levels and meteorological data. In particular, this method will allow for the examination of the effects of asthma on lung function and will also consider the difference between asthmatics and non-asthmatics with respect to the relationship of pollution and meteorology to lung function. Similar procedures will be used to analyze the symptomatology information using dichotomous acute health symptom responses.

Preliminary Results. The results of the monitoring program clearly show that the camp area was affected by transported air pollutants. Ozone levels showed typ-

ical diurnal variations with elevated midday concentrations. The Ontario ambient air quality standard of 80 ppb for 1 hr O_3 , was attained or exceeded on 5 of 10 days. The peak value attained was 114 ppb on day 4 of the study. Respirable fraction sulfates were highly variable and ranged from 10 to $26 \mu\text{g}/\text{m}^3$. Sulfate as sulfuric acid was usually very low.

Trajectory analysis was performed to determine the possible source regions of transported air pollutants which contributed to the ambient conditions monitored. On July 3 and 5, it was observed that two distinct air masses, of different origins, impinged on the research site. Warm moist air from the south, and cool, dry air from the west determined the meteorological and pollution conditions on these days.

Preliminary analysis of the health data suggests that minimal, if any, acute health effects can be attributed directly to the air pollutants monitored. The health responses between asthmatic and non-asthmatic subjects are currently being compared. The responses of asthmatics are confounded by their daily use of medication. Of interest, five asthma attacks occurred during the study interval, three were during the overnight period

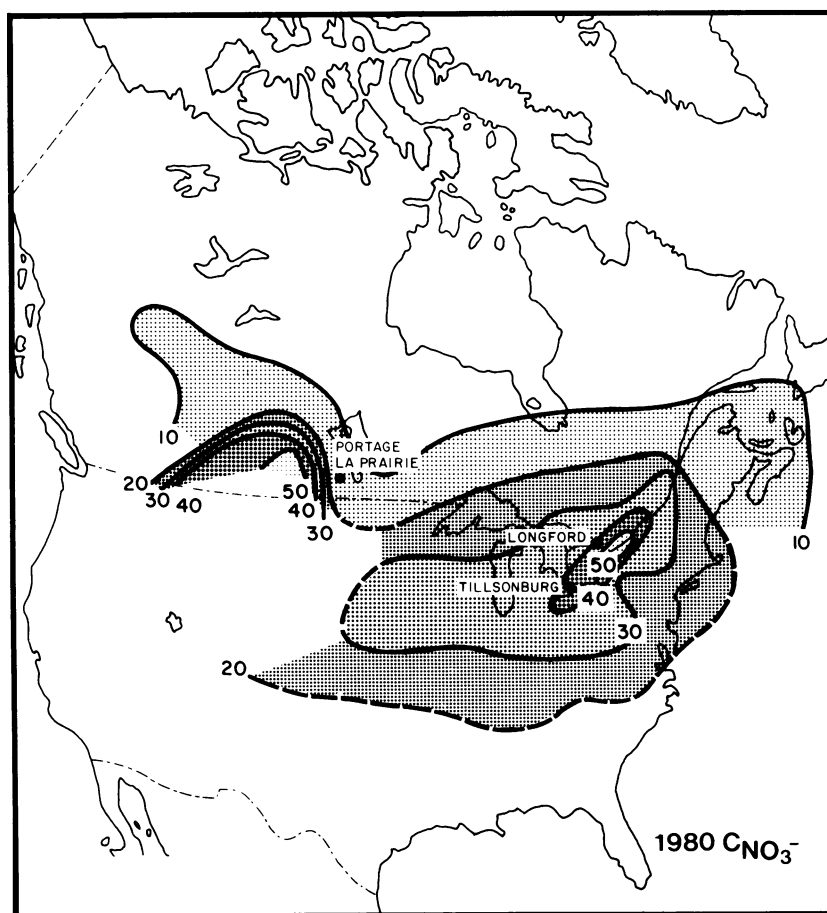


FIGURE 6. Precipitation amount-weighted mean nitrate ion concentration for 1980 ($\mu\text{mole}/\text{L}$) (10).

and two during the day. All attacks occurred in the latter portion of the study namely day 6, 7, and 8.

Future Directions. The 1983 study has provided a functional experimental model to study acute health responses to mixtures of pollutants along with continuous environmental monitoring data. Although the preliminary data suggest minimal health effects at these low levels of pollution, future studies will focus on other regions during periods when higher LRTAP levels are known to occur. It is anticipated that the camp research site will be continued, with an effort also being made to measure pulmonary function during episodes of high pollution.

Systematic assessments of medication usage (frequency and dosage) will be employed along with spirometric tests of greater sensitivity. Assessments of airway reactivity will be performed to document responsive trends in populations that will include non-asthmatic children and the elderly, in several areas and periods of elevated air pollution.

Chronic Study

Design. The design of this epidemiological study was cross sectional with two sampling periods, one in the fall of 1983 and one in the winter of 1984. The pur-

pose of the investigation was to assess the potential chronic health effects of exposure to LRTAP pollutants in 7- to 12-year-old children.

Several health indices were utilized including an initial self-administered health questionnaire, biweekly health diaries done through telephone interviews, and pulmonary function tests. The questionnaire was used to ascertain and account for domestic confounders and to gather information on the upper respiratory illness history of the child. The diary yielded data on the perceived acute symptoms experienced by the child during the course of the study. The lung function tests were performed to give a quantifiable measure of the pulmonary health of the child.

The towns were chosen as study sites to represent a high and low LRTAP area. As shown in Figures 5-7, the sulfate, nitrate, and pH of rainfall precipitation are much more acidic in Tillsonburg than Portage la Prairie. Therefore the towns were anticipated to reflect the desired criteria.

Air quality monitoring was conducted both indoors and outdoors at the study site, and environmental data from regional sources were also gathered. In addition, meteorological data were collected to complete the atmospheric data base.

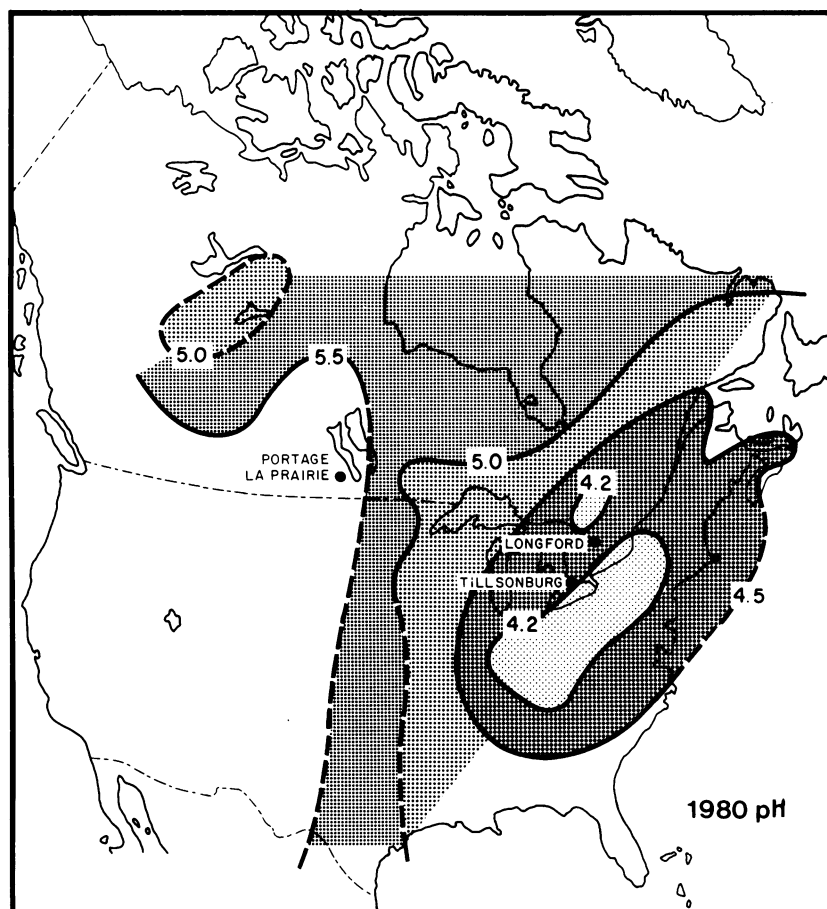


FIGURE 7. Precipitation amount-weighted mean annual pH in North America for 1980 (10).

Preliminary Results. The towns of Tillsonburg, Ontario and Portage la Prairie, Manitoba were comparable in terms of socioeconomic status, maternal smoking habits, primary heating fuel usage, age and sex distributions, presence of early respiratory illness, history of parental respiratory illness, and perceived respiratory illness as reflected by the diary. The towns were not comparable with respect to the prevalence of allergies (27% for Tillsonburg, 14% for Portage la Prairie); chest cold (39% for Tillsonburg, 33% for Portage la Prairie); auxiliary fuel usage [Portage la Prairie uses more electricity (20% vs. 12%) and less wood (19% vs. 26%) than Tillsonburg]; cooking fuel [Tillsonburg uses more gas (14% vs. 1%) and less electricity 84% vs. 98%) than Portage la Prairie]; and paternal smoking (55% for Tillsonburg and 44% for Portage la Prairie). There is also an increased percentage of children in Tillsonburg receiving antibiotics following a visit to a doctor when compared to children from Portage la Prairie.

A preliminary statistical analysis indicates that there may exist a difference (adjusted for the age, sex, and height of the child) between towns in several parameters relating to lung function. Caution should be taken in interpreting these preliminary results since other possible confounders, such as paternal smoking, auxiliary heating, total amount smoked in the home and probably most important, allergies, have not yet been considered in the analysis.

This observed difference between towns may be of biological significance. At this point in the analysis, the data do not suggest any substantive health effects due to LRTAP exposure, but the trend observed may suggest a health hazard that may become more apparent as the duration of exposure increases.

Air quality monitoring has indicated that the two towns differ in ambient concentrations of several air pollutants (Table 7). Tillsonburg has been shown to have higher average values for NO₂, O₂, total respirable particulates (10 µm), SO₄, and NO₃.

The various meteorological measurements reflect the differences between the towns. Portage la Prairie has lower winter temperatures with larger diurnal variation. Wind direction in Portage la Prairie is generally from the northwest or south, while Tillsonburg receives its wind flow from southwest or west. No major atmospheric anomalies occurred during the investigation.

Table 7. Average pollutant concentrations found in study towns.

Pollutant (concentration)	Portage	Tillsonburg
NO (ppb) ^a	5.94	4.42
NO ₂ (ppb) ^a	7.78	10.43
SO ₂ (ppb) ^a	0	7.92
TRP (µg/m ³)	40.49	45.49
SO ₄ (µg/m ³) ^{a,b}	0.72	2.75
NO ₃ (µg/m ³) ^{a,b}	0.54	1.24

^aSignificantly different between towns ($p < 0.001$).

^bThe sulfate and nitrate values were extracted from the respirable fraction of the particulate samples only.

Future Directions. Following this initial study an expanded investigation is currently planned. It will again be cross-sectional in design and will be conducted in ten separate communities.* The health indices discussed previously will be monitored again in children in each of the selected towns. Extensive indoor air monitoring within the schools and regional ambient air quality sampling will be performed and standard meteorological information will be gathered.

Related Canadian Studies on Predeposition Effects

There have been a number of studies undertaken by various researchers in Canada relating to the health effects of air pollution (Table 8). The chamber study and environmental exposure studies of Silverman (26,27) suggest that asthmatics are more sensitive even though the magnitude of response may have been masked because of their medication. A preliminary report by Pengelly et al. (28) suggests that factors associated with poor respiratory health were prevalent in areas of poor air quality. The other studies have shown some effects with exposure to air pollutants and also the impact of smoking (29–32).

Postdeposition (Indirect) Effects

Acid deposition has been shown to have deleterious effects on water quality and food through direct atmospheric deposition of the pollutants, the mobilization of metals such as cadmium, lead, and aluminum from generally fixed sites such as ores and insoluble deposits, and the transformation of a substance to its more toxic forms (mercury to methylmercury). In addition to these, acidified water may be corrosive to sensitive tissues, and it may also cause increased leaching of metals from pipes in which water has been standing.

Mobilization of Metals

One of the metals that has been of particular concern in Canada has been mercury. Although natural sources contribute the major portion of mercury to the aquatic environment, direct atmospheric depositions can be significant on a regional scale and acidification does appear to increase the bioavailability of mercury. Elevated levels of mercury have been found in fish taken from lakes which were characterized by low alkalinities and were remote from local sources of pollution.

The bioaccumulation of mercury in fish is potentially a problem for all Canadians. However, the Department of National Health and Welfare, because of its responsibilities for the health care of Indian and Inuit residents

*Portage la Prairie and Tillsonburg will be included in this study. Thus, a longitudinal study will be formed which builds on the previous cross-sectional chronic study.

on reserves and other crown lands in the provinces, has been particularly concerned about the health effects of environmental mercury since problems of mercury pollution were identified in Northwest Ontario and Northwest Quebec in the early 1970s. Between 1961 and 1970, large quantities of inorganic mercury were discharged into river systems by chloralkali plants associated with the pulp and paper industry (33). The finding that inorganic mercury is methylated by microorganisms in

river and lake sediments (34) and the subsequent bioaccumulation up the food chain is of particular concern with respect to Indian and Inuit people of Canada, who commonly use fish, game, and sea mammals as a primary food source.

A program of surveillance, monitoring and health education was set up and mercury levels in blood and hair determined on residents of 350 communities. In the period ending in 1978, 66 individuals were found to have

Table 8. Related Canadian studies on predeposition effects.

Author	Pollutant	Subjects	Design/exposure	Results
Pengelly et al. (28)	General urban air pollution	Children, 7–10 years of age	Cohort of 3200 children Children administered lung function tests and parents were asked to complete a questionnaire	Preliminary report Factors associated with poor respiratory health were prevalent in areas of poor air quality
Bates and Sizto (29)	SO ₂ , O ₃ , NO _x , soiling index and temperature	General population of S.W. Ontario	Published hourly pollution data correlated with hospital admission data for 1974, 1976, 1977, 1978	For July and August, significant excess respiratory admissions were found to be associated with SO ₂ , O ₃ , and temperature
Silverman et al. (26)	SO ₂ , NO _x , TSP	Asthmatics/nonasthmatics	Diaries and pulmonary function was assessed over the study period Personal monitors as well as fixed station monitoring were used to estimate exposures	In asthmatics pulmonary function changes were associated with personal NO _x exposure in the nonheating season Asthmatics showed greater responses to pollutants than normals
Silverman (27)	Ozone	Asthmatics/nonasthmatics	Environmental chamber with 2 hr exposure to 0.25 ppm O ₃ and normal air Lung functions tests performed before, during, and after exposure	Although most asthmatics were taking medications to control symptoms, they showed greater variability and decreased pulmonary function
Newhouse et al. (30)	SO ₂ , H ₂ SO ₄	Healthy adults	Controlled chamber studies SO ₂ levels were 5.0 ppm and H ₂ SO ₄ exposures were 1 mg/m (MMD 3 µm)	Mucociliary clearance was enhanced by both exposures Pulmonary function was decreased more by SO ₂ exposure SO ₂ response was more reflexive while H ₂ SO ₄ showed more evidence of a direct effect
Neri et al. (31)	SO ₂ , TSP	Residents of Sudbury and Ottawa, Ont. over 15 yr of age	Attempted to separate the relative importance of age, smoking, location, duration of residence, occupational history and duration of occupational exposure in the development of chronic respiratory disease	Residents of Sudbury had more chronic bronchitis and reduced respiratory function The most important factor for chronic bronchitis in Ottawa was smoking while in Sudbury there were four factors; age, smoking, occupational history, and duration of residence
Sharratt and Cerney (32)	General urban air pollution	Grade 1 children, ages 6–8 yr	Children residing in Windsor and London were tested	Reported decreased pulmonary function and increased incidence of respiratory illness in Windsor

blood mercury levels between 200 and 500 ppb (35), the range in which symptoms may be seen in the most sensitive individuals (36). Five people had levels in excess of 500 ppb. By 1982, only three people had levels ranging from 200 to 399 ppb, and no one exceeded this level (37). Although severe methylmercury poisoning, (Minamata Disease) was not found, milder forms of mercury poisoning, although difficult to prove conclusively, may be occurring (38). The lakes and rivers in these areas of the Canadian Shield are highly sensitive to acid deposition and any increased mobilization and transformation of mercury could be devastating to these native populations.

Increases in Toxic Elements in Water Supplies

A study in which the effects of standing time on the leaching of metals from the plumbing systems of cottages on acid-rain sensitive lakes in Central Ontario was conducted by the Department of National Health and Welfare (39). Metal concentrations as well as leaching rates were measured in the lake water and in the water from the tap following passage through the plumbing system.

The concentrations of copper, lead, zinc, and cadmium increased dramatically in lake water which was acidified. Maximum values of 4560 µg/L Cu; 478 µg/L Pb; 3610 µg/L Zn; and 1.2 µg/L Cd were measured in water that had stood for 10 days in the plumbing system. Maximum rates of leaching of Cu, Pb, and Zn were observed after 2 hr standing time, and levels continued to rise over the 10-day period. The levels of Pb and Cu exceeded the maximum acceptable concentration as recommended in the Canadian drinking water guidelines (Pb, 50 µg/L; Cu, 100 µg/L). It was shown that these levels decreased by 95% in the third liter of water sampled, leading to the conclusion that flushing the distribution system daily would minimize any potential risk of developing health problems.

Corrosivity of Acidified Water

As a result of the declining pH of many natural waterways, concern has been expressed that human activities in these waters may be adversely affected. The acidity level of lakes and streams has exceeded the recommended guidelines for drinking water. However, the pH guideline was developed to prevent corrosion and incrustation of water distribution systems and did not take into account any health considerations.

Due to the seriousness of the decline in pH, the possibility that sensitive tissues such as the eye, might be damaged was investigated in rabbits.

A study conducted in which acidic lake water (pH 4.5–5.18) was instilled in the eyes of rabbits and the contralateral eyes were exposed to more natural lake

water (pH 6.2–6.4). There were no significant clinical or morphological differences observed, and the authors concluded that short-term exposures to lake water with a pH as low as 4.5 did not appear to be related to any adverse ocular reactions (40).

Conclusions

Acid deposition from both Canadian and American sources occurs in Canada. In the acute and chronic exposure studies conducted by the Department in 1983 and 1984, monitoring data showed that there was deposition of transported air pollutants and that there were both acute episodes of exposure at the summer camp as well as chronic exposure in Tillsonburg. Inconsistencies in indoor-outdoor gradients indicate the need to obtain more precise information to enable accurate estimates of exposure. Preliminary analysis of the pulmonary function data from both the acute and chronic studies have not revealed any major detrimental health effects. However certain trends in the data from the chronic study must be further analyzed before final conclusions can be drawn.

It has been shown that acidification of lake water may lead to detrimental effects on water quality through leaching of metals from the plumbing system. The increased acidity may also result in mobilization of heavy metals and ultimate bioaccumulation of toxic metals such as mercury.

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